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## **Field Olfactometry Assessment of Dairy Manure Land Application Methods**

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**Abstract.** *Because odor potential is poorly correlated with measured concentrations of component gases, human sensory assessment (olfactometry) remains the ultimate means for quantifying agricultural odors. Field olfactometry measurements vary with wind velocity and source distance. To minimize this variability, dairy manure slurry was applied in a 10-ft swath to grassland in 200-foot diameter circles. Nasal Ranger<sup>®</sup> Field Olfactometer (NRO) instruments were used to collect dilution-to-threshold (D/T) observations from the center of each circle using four odor assessors taking four readings each over a 10-min period. The Best Estimate Threshold D/T (BET<sub>10</sub>) was calculated for five manure application methods and an untreated control. Field odor panel observations were performed before application and at <1 h, 2-4 h, and ~24 h after manure spreading. Whole air samples were simultaneously collected for laboratory dynamic olfactometer evaluation using the triangular forced-choice (TFC) method. The BET<sub>10</sub> of NRO data composited for all measurement times showed D/T levels decreased in the following order ( $\alpha = 0.05$ ): surface broadcast > aeration infiltration > surface + chisel incorporation > direct ground injection  $\approx$  shallow disk injection > control, which closely followed laboratory TFC odor panel results ( $r = 0.83$ ). We conclude field olfactometry can be useful for quantifying agricultural odor emissions but multiple assessors and observations, strict compliance with established protocols, and careful data analysis are essential.*

**Keywords:** dynamic olfactometer, field olfactometry, manure application methods, odors.

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## Introduction

Odor measurement is difficult because no practical instrument has been developed that measures all the various aspects of odors. Agricultural odors are complex and transient. Over 160 compounds have been identified in manure or the surrounding air (O'Neill and Phillips, 1992). Each individual compound contributes to the overall character either by making the emission more offensive, easier to detect, or harder to measure. Reduction of odor offensiveness may not be directly correlated with efforts to suppress individual components such as ammonia or hydrogen sulfide. Thus there is a need for methods that directly measure odors.

Employing the human nose as the sensor (olfactometry) is considered the most reliable means of quantifying odors (Miner, 1995). The human nose is exquisitely equipped to detect odor, but personal preferences affect what is considered acceptable or offensive. Modern instruments can measure many compounds that make up an odor, however odor is a combination of numerous compounds with interactive effects that influence human perception. Despite inherent limitations, olfactometry has the ultimate benefit of capturing the "total effect" human experience (Gostelow et al., 2003).

Despite efforts to be objective, human odor evaluation can be influenced by anxiety, distraction, fatigue, health status, personal comfort, and/or visual cues. Special techniques are required for sensory evaluation of odors. For outdoor environments, local weather conditions play an important role in odor release and transport, and the ability to control/manage factors that may differentially influence odor assessors is limited. Accordingly, laboratory-based triangular forced-choice olfactometry (TFC) measurement is presently considered to be the best available technology (Zang, 2002) and is the undisputed "gold standard" for sensory quantification of odors. Laboratory TFC evaluation is believed to give "better accuracy, reproducibility, and statistical reliability" than other methods (USEPA, 1996). However, sample preservation and potential adulteration introduced by sample bags (typically Tedlar™) are continuing challenges.

Until recently, odor quantification via olfactometry lacked standardized methods. In the 1980s several European countries launched an effort to develop international standards to provide uniform, objective and repeatable olfactometry observations. In 2003, the Comité Européen de Normalisation (CEN) published the standard, CEN EN13725 (CEN, 2003), which has been adopted by the European Union and received widespread acceptance for threshold olfactometry evaluation (St. Croix Sensory, 2005). This standard provides criteria for equipment design and materials, calibration, sample sizes, and strategies for capture of whole-air samples. Standards for odor panel selection, qualification, and size were specified. Procedures for calculation of detection threshold (DT) from a set of panel responses and exclusion of outlier observations are detailed. Requirements for triangular forced choice (TFC) odor sample presentation (the preferred method) and replications are specified. Triangular forced-choice olfactometry in accordance with EN13725:2003 provides objective and repeatable measurements that are comparable across laboratories. However, TFC olfactometry is expensive and time-consuming, and real-time field measurements are not possible.

In the late 1950s, the U.S. Public Health Service sponsored research leading to the development of a relatively inexpensive, hand-held device for sensory detection of odors in the field, using the same fundamental dynamic dilution approach as laboratory olfactometry. The first commercially available field olfactometer was manufactured by the Barneby-Sutcliff Corporation and was marketed under the name, Scentometer®. The Scentometer® produces known odor dilutions by mixing ambient (odorous) air with carbon-filtered (odor-free) air, which is sniffed and directly evaluated in the field.

Field olfactometry dilutions-to-threshold (D/T) observations offer several advantages over laboratory TFC measurements: (1) lower detection levels (most dynamic olfactometer labs advertise a detection floor of 5-10 D/T); (2) real-time measurements; (3) elimination of sample collection, transport, and the attendant sample preservation issues; and (4) lower cost per sample (McGinley and McGinley, 2003). Proponents recommend its use as a proactive monitoring tool for agriculture to: (1) monitor routine operations; (2) compare operating practices; (3) document specific events or odor release episodes; (4) determine facility baseline status; (5) investigate control practice effectiveness; and (6) select odor sources for control measures. Where D/T standards are established, field olfactometry is also used as a regulatory tool to verify complaints and determine compliance at property lines or in the neighboring community (McGinley and McGinley, 2003).

Field olfactometry is attractive because of the relatively low cost and convenience (Miner, 1995). A recent study by Brandt et al. (2007) found that the Nasal Ranger Field Olfactometer (NRO) can be a very useful management tool to aid producers and agricultural advisers in decision-making processes involving the odor potential of production units and practices, and in evaluating odor reduction strategies. These researchers note that meaningful results are contingent upon strict methodological protocols and data analysis. Since field observations are influenced by a number of uncontrollable factors (e.g. wind direction, wind speed, and visual suggestions), minimizing the influence of such factors improves confidence in findings (Agnew et al., 2006). Brandt et al. (2007) recommend multiple odor assessors and observations, and Best-Estimate Dilution Threshold (ASTM-679-04) data evaluation for decisions involving costly management strategies.

Because field olfactometry is increasingly used to quantify and regulate odor emissions from agricultural operations, it is crucial to determine how this technique can be used to obtain meaningful measurements. Thus, our primary goal was to investigate the use of field olfactometry for quantifying odors associated with five methods for dairy manure slurry application to grassland. Odor emissions from manure spreading have become a major concern in some areas. Spreading equipment and methods have far-reaching implications for a farmer, affecting operating costs, fertilizer requirements, and the likelihood of nuisance complaints from nearby residents. Critical to the experiment was the design of a protocol that would minimize odor sampling variability. Moreover, it was important to understand how field olfactometry measurements compared to data collected via the internationally accepted TFC methodology. Ultimately, we hoped to understand how field olfactometry should be conducted to yield meaningful data for evaluating management practices to mitigate malodors associated with manure management.

## **Materials and Methods**

### ***Manure characterization***

Manure was obtained from a local dairy farm where it is scraped daily and placed in a slurry storage facility for subsequent field application. Table 1 shows the manure characteristics, which are typical for Pennsylvania dairy operations. In this study, manure was drawn from the storage into a tractor-drawn manure-tanker unit, equipped to accommodate various interchangeable field spreading implements.

### ***Manure application***

To minimize the influence of variable wind direction and source distance, dairy manure slurry was applied at a uniform rate of 6,000 gallons per acre in a 10-ft swath to sod, in 200-foot

diameter circles. An untreated area (control) was also established where odor observations were made in the absence of manure. Manure circles were carefully located to avoid cross-contamination among treatments.

Odor emissions were measured for five methods of manure application:

1. *Surface broadcasting*: Manure was applied from a toolbar with six outlets placed above splash plates.
2. *Surface plus chiseling*: Following broadcast application, the ground was immediately (<15 min) chisel plowed to ~20 cm depth.
3. *Aeration infiltration*: Manure was surface banded in 5-cm widths behind aeration tines that cut 6-cm slots into the soil, so that some manure infiltrated into the slots.
4. *Shallow disk injection*: A cutting disk created a ~10-cm slot in the soil and manure deposited in the slot using drop tubes. Slots were then closed with trailing disc sealer-wheels.
5. *Direct ground injection (DGI)*: Slurry is pressurized (5-8 bars), distributed to nozzles, and injected in pulses to form discontinuous cavities (5-10 cm deep) beneath the soil surface.

### ***Field olfactometer measurements***

Odor panel observations were made the six treatments at 0 hr (pre-application), 1 hr, 2 to 4 hrs, and ~24 h following manure application. At each location, four qualified odor assessors (EN13725:2003) were positioned in the center of the manure circle and equipped with individual NRO units, which were used to determine the odor D/T value of the field. For each sampling event, field D/T observations were collected over a 10-min (nominal) period under the supervision of a test administrator (TA), who ensured protocol compliance and recorded all observations.

The NRO field procedures, detailed in Brandt et al. (2007), are briefly summarized here. Odor panelists wore ½-face carbon filter respirators to prevent odor desensitization. At each observation location, assessors were placed as close together as possible (shoulder-to-shoulder), facing the predominant wind direction. The TA set each NRO unit to a blank setting (100% carbon filtered air), and signaled panelists to collectively remove their respirators and begin D/T observations without inhaling (smelling) ambient air during the exchange. Assessors each operated their own NRO units, at their own pace. When an assessor noted a *detect* reading, the NRO unit is removed from the face, the respirator is put on, and the assessor waits until other panelists have completed their current observation (typically <1-2 minutes). When all assessors were finished, the TA recorded the NRO dilution dial D/T setting on each unit and then re-set the dial to another blank position (as appropriate), and the process was repeated. In all, four sequential D/T readings are obtained by each of the four panelists, resulting in 16 individual measurements over the ~10 observation period. Care was taken to ensure that odor panelists were unaware of the D/T level on their unit, or that of fellow assessors.

Odor assessors were not told, nor could they observe, the manure application equipment/methods being used. Assessors were also prevented from seeing treated areas from closer than ~100 feet (center of each manure circle). Wind speed and predominant wind direction were recorded during each observation location, along with odor characterization (odor wheel descriptors by St. Croix Sensory, 2003). Other weather data (temperature, relative humidity, barometric pressure, cloud cover, and precipitation) was also recorded on the day field measurements were collected.

### ***Laboratory-based triangular forced-choice olfactometer measurements***

During the 2-4 h observation period, whole air samples were collected for each treatment in preconditioned 10-L Tedlar™ bags. Samples were obtained at face-level (~1.5 m) immediately adjacent to assessors using a suitcase vacuum chamber unit employing the lung principle. Approximately 8-L of whole air was collected during each panel observation set, representing a composite sample for each ~10-min sampling event. In all, six whole air samples were secured and preserved (room temperature, dark) for odor panel evaluation the following day. Laboratory TFC detection threshold (DT) and recognition threshold (RT) levels were determined with an Ac'Scent International Dynamic Olfactometer (CEN, 2003) within 30 h of sample collection.

### ***Data Treatment***

Field olfactometer data were processed to determine a Best Estimate Threshold (BET) odor D/T value for each odor panel observation data set (16 observations) using the method detailed in ASTM E679-04. This method, developed for laboratory-based olfactometry, was judged to be an effective and valid way of processing multiple DFO D/T observations, which simulate the YES/NO laboratory threshold procedure. In this method, the geometric mean of the last *non-detect* dilution ratio and the first *detectable* dilution ratio is determined for each assessor [known as the Individual Threshold Estimate (ITE)]. The overall panel BET is then determined as the geometric mean of all ITE values. Since this method was applied to field olfactometry observations collected during a 10-min period, we introduce the term BET<sub>10</sub> to distinguish this calculated value apart from lab-based olfactometry results reported elsewhere in the literature. Laboratory TFC odor panel results were evaluated in accordance with EN13725:2003 calculation and retrospective screening procedures. In this study, TFC odor panel threshold results are identified as  $Z_{ITE,pan}$  following EN13725:2003 terminology. Basic statistics (mean, median, mode, standard deviation, coefficient of variation, minimum value and maximum value) were determined using log transformed data.

Statistical evaluations were performed to assess the effect of manure application methods on odor panel results using SAS (2003). Main effects due to method of manure application, interaction and random effects due to time of measurements, ID, DFO versus TFC methods, and replication were analyzed using the PROC MIXED covariance test. Least significant differences were determined when the effect of application method on odor panel results was found to be significant ( $\alpha = 0.05$ ). Relationships with environmental variables were assessed using Pearson correlation and stepwise regression analyses. Tests for normal distribution were performed using Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises and Anderson-Darling tests, and SAS program analyses. Variance analyses were performed on odor panel data from the Ac'Scent instrument (TFC) and NRO field observations, which were found to be normally distributed ( $p < 0.0001$ ).

## **Results and Discussion**

### ***Influence of Manure Application Method***

Table 2 shows the log BET<sub>10</sub> values for application methods and sampling times and the composited data for the four sampling times. For comparison, the actual BET<sub>10</sub> values are plotted in Figure 2. Time zero (Table 2, Figure 2) readings were collected at the six sites prior to manure application. These data indicate that with one exception, the log BET<sub>10</sub> values were identical, and that 4 of 5 application sites had background D/T odor levels not statistically different from the control site. The log BET<sub>10</sub> value for the site where slurry was applied using

the aeration infiltration device was statistically higher than other sites. The other sites were surrounded on all sides by open grassland, while the aeration infiltration treatment circle was located ~30m from the normally downwind perimeter of a wooded area. During this experiment, the predominant wind originated out of the NE, rather than the typical W (or NW) and natural emissions from the woodlot (earthy/ leaf litter character) were noted at this one odor circle location during background odor panel observations. *Grassy* or *no odor* was most often reported as *background* at other treatment locations.

Readings from the untreated control location were statistically lower than values for any of the manure application methods. This is consistent with expectations and lends credence to the use of field olfactometry for quantifying odors from manure application activities. Only the DGI method 24 h after application indicated that the odor D/T level had dissipated to the point that it was no longer statistically higher than the untreated control, indicating the greater effectiveness of this technique for controlling odors associated with manure application.

The log BET<sub>10</sub> D/T values for the three sampling times and the composite values (Table 2, Figure 2) have some features in common. At all sampling times, the surface broadcast application had the highest log BET<sub>10</sub> values. Many other researchers have documented lower odor emissions for application methods that involve some incorporation into, or mixing with, the soil (Pain et al., 1991; Moseley et al., 1998; Hanna et al., 2000; Chen et al., 2001). However, in our study, broadcast application was not always statistically higher than every other application method. For example, at the <1 h and 24 h observation times, the aeration infiltration method exhibited statistically similar odor levels. And at the 2-4 h time, the effect of chiseling following surface application did not produce statistically lower odors compared to surface broadcast method. Yet, all of the methods resulted in statistically lower odor production for *at least one* observation time.

Noteworthy is the relative inability of the aeration infiltration device to significantly mitigate manure odors. This device consists of rotating knives which cut the soil surface followed by manure spreading which fills the cuts in the soil. For two time periods (<1 h and 24 h) aeration infiltration was the only application method which had odor D/T levels statistically similar to surface broadcasting of the manure. From the depiction in Figure 1, aeration infiltration could be described as a partial incorporation method. In work conducted at the USDA Forage Research Center reported by Johnson (2007), research found ammonia emissions for different application methods followed the order: surface broadcast > aeration device > injection. However, Bonnefoy (2001) found no difference in odor concentrations between surface application and an aerator device using a dynamic olfactometer with a forced-choice method. Lau et al (2003) found statistically lower odor strength 0.5 h after application of swine manure for an aeration infiltration spreading device compared to conventional splash-plate surface application. At later observation times (1.5 and 2.5 h) the gap between the measured odors for the two methods decreased. Our <1 h observations (Table 2) are consistent with the results of Chen et al (2001) who found that odor concentrations immediately after manure application were not statistically different for aerator incorporation and surface banding with a dribble bar.

The data does not permit an unequivocal assessment of the effect of surface chiseling on odor generation. The 2-4 h data (both field and laboratory olfactometry) indicated that chiseling following surface spreading did not reduce odors. However, odor levels at the <1 h and 24 h times were significantly different than the broadcast application. Supporting the ineffectiveness of chiseling is the work of Pain et al (1991) who reported odor emission during the first hour after spreading were similar for plowing with a rigid tine instrument versus simple surface application.

Two application methods (shallow disk injection and DGI) consistently generated lower odors than the surface broadcast method. Both methods result in a significant proportion of the manure being covered by soil. With DGI, the manure is injected in pulses to form discontinuous cavities beneath the soil surface (Morken and Sakshaug, 1998). This method would ostensibly involve the least amount of slurry-atmosphere contact following application. This manure application technique has been shown to result in lower ammonia emissions relative to surface broadcasting and band spreading (Morken and Sakshaug, 1998). In our study, the DGI had the lowest odor potential according to the composited field olfactometry data (Table 2, Figure 2) and the laboratory dynamic olfactometer DT results (Table 3). Except for the <1 h observations, the shallow disk was equal to, or better than, the DGI in reducing odors compared to surface spreading.

Figure 3 shows the effect of time on odor release, considering all application methods (composited) at the time indicated. These results are consistent with the expectation that odor potential is greatest immediately after application and then decreases with increasing time. For example, ammonia emissions are highest right after manure application (Johnson, 2007). Lau et al (2003) found odor strength from pig manure spreading on grassland for time following application in the order: 0.5 h > 1.5 h > 2.5 h. Hanna et al (2000) reported that odors measured one day after swine manure application (various methods) were comparable to odors from untreated soil. Our results using dairy manure do not support such a conclusion (Figure 2, Figure 3, Table 2) with a single exception. The log BET<sub>10</sub> values for the DGI method were statistically similar to the control plots at the 24-h observation time (Table 2, Figure 2).

### ***Comparison of Field versus Lab-based Olfactometry Results***

Figure 4 compares laboratory TFC olfactometry Z<sub>ITE,PAN</sub> DT and RT results with the field BET<sub>10</sub> D/T findings for the 2-4 hr observation period. Noteworthy is the large difference between laboratory DT and field D/T odor panel results, which in most cases are more than an order of magnitude greater with TFC measurement. Newby and McGinley (2004) likewise found laboratory TFC odor panel levels to be much higher than field olfactometer readings, concluding that a laboratory DT of 110 was approximately equivalent to a field olfactometer D/T level of 7:1. Though differences were not as pronounced, Bokowa (2008) reported that the NRO device gives significantly lower odor detection threshold values (2x to 3x), than ambient air sampling with laboratory assessment. Bokowa (2008) attributes the discrepancy to three contributing factors: (1) inadequate removal of selected odorants (e.g. sulfur compounds, dimethylamine, trimethylamine) by the NRO carbon filters, (2) single person field measurements, and/or (3) NRO assessor odor fatigue with time.

We do not believe the factors cited by Bokowa played a role in our study for several reasons. All NRO assessors wore ½-face carbon filter respirators when in the vicinity of manure emissions. When initiating odor circle D/T observations, panelists exchanged respirators for their individual NRO units without breathing unfiltered ambient air. Thus assessors were only exposed to manure odors during D/T observations, and then only when observing a threshold *detect* reading. At the conclusion of each observation set, assessors were instructed to remove their masks and characterize the unfiltered air. Without exception, all panelists indicated that they could not detect ambient odors while wearing the respirator or the NRO unit when set at a blank position (100% carbon filtered air). Moreover, assessors often commented that they were surprised with the strong odor intensity of ambient air during the initial observations after manure spreading. At least 30 min elapsed between exposures to full strength malodorous air, providing ample time for nasal sensitivity recovery. Accordingly, we conclude the respirator and NRO unit carbon filter cartridges were effective in removing odorants. Because we used multiple assessors and observations, and BET (ASTM E679:2004) NRO odor panel data processing,

Bokowa's (2008) single-observer rationale is inapplicable. Detailed statistical analysis of the NRO field data collected through the course of this experiment revealed no trends in reported D/T levels that would suggest *desensitization* of odor assessors, and we therefore reject this explanation as well.

Other possible explanations for greater laboratory olfactometry odor panel DT levels relative to field NRO odor panel results include: (1) the use of TFC (lab) versus Yes/No (field) odor panel methodologies, (2) ultra-clean odor-free laboratory environment versus inherently tainted conditions in the field, (3) temperature differences between field (12<sup>o</sup> C) and laboratory (21<sup>o</sup> C) odor panel conditions at the time of our experiment, and (4) adulteration of whole air samples related to Tedlar™ bag containers and holding time (~24 h). It is also noteworthy that many people who use the NRO will not register a *detect* (Yes) response until they notice some character of the odor. Such a response is more appropriately identified as the *recognition threshold*, which is typically about ½ of the DT level in laboratory olfactometry (Figure 4). This later explanation would seem to account for much of the discrepancy between lab and field olfactometry thresholds noted by Bokowa (2008), but alone, cannot explain the magnitude of difference in our work, which is more similar to the findings of Newby and McGinley (2004).

Despite the numerical differences between lab and field odor panel results, it is noteworthy that the odor emission *trend* for the various land application technologies is similar (Figure 4). Since laboratory TFC olfactometry is considered the *gold standard* for threshold olfactometry, we conclude that the NRO field protocol employed in this study was an effective tool. Indeed, one might even argue that the NRO technique presented here may be more effective than the laboratory TFC method when quantifying low threshold downwind emissions. For example, statistical analyses of field olfactometry BET<sub>10</sub> results for various application methods, composited over time, enabled discrimination of five statistically different odor emission categories (Figure 2). This was made possible, at least in part, by the number of observations collected in the field. Laboratory TFC measurements were limited to only six samples for the 2-4 h event, due to logistical constraints and cost. As a result, laboratory odor panel DT and RT results provided only three or four statistically different odor emission categories, respectively (Figure 4), which are specific to the 2-4 h period following manure spreading.

## Summary and Conclusions

The frequency of odor complaints and lawsuits is increasing in the US as the population migrates to rural communities where agricultural operations are located. Some states are adopting odor guidelines which include odor limits based on field olfactometry. We analyzed odors associated with different dairy manure slurry application techniques in an effort to develop and refine protocols for obtaining objective and repeatable field odor measurements.

Because field odor measurements are influenced by changing wind speed and direction, the *odor circle* experimental configuration is useful for investigating odor emission differences based on manure application method. However, results suggest that a buffer zone of similar topography and land usage should be maintained around odor circle treatment areas for this protocol. For low D/T odor sources, different near-by “natural” landscape features (e.g., woodland) may influence odor quantification if located upwind from the odor panel.

The field olfactometer log BET<sub>10</sub> values ( $\alpha = 0.05$ ), for all measurement times composited, indicated odor D/T levels decreased in the following order: surface broadcast > aeration infiltration > surface + chisel incorporation > direct ground injection  $\approx$  shallow disk injection > control which closely followed visual estimates of the amount of manure remaining on the



surface. Quantification of the manure remaining on the surface for the different application methods using measures such as the manure exposure index (Rahman et al., 2005) would greatly enhance the value of similar future studies. Odor levels from the direct ground injection methods were statistically indistinguishable from levels observed for the untreated control one day after application.

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**Table 1.** Manure characteristics.

Parameter	Value <sup>1</sup>
pH	8.01
Solids (%)	7.71
	<b>g kg<sup>-1</sup> (dry basis)</b>
Total Nitrogen	45.78
Ammonium N (NH <sub>4</sub> -N)	16.93
Calculated Organic N	28.85
Total Phosphate (P <sub>2</sub> O <sub>5</sub> )	14.27
Total Potash (K <sub>2</sub> O)	43.77
Total Calcium (Ca)	23.74
Total Magnesium (Mg)	8.75
Total Sulfur (S)	4.47
Total Copper (Cu)	0.26
Total Zinc (Zn)	0.39
Total Manganese (Mn)	0.26
Total Iron (Fe)	1.56
Total Sodium (Na)	7.78
Total Aluminum (Al)	0.91

<sup>1</sup> Penn State Agricultural Analytical Services Laboratory using standard methods

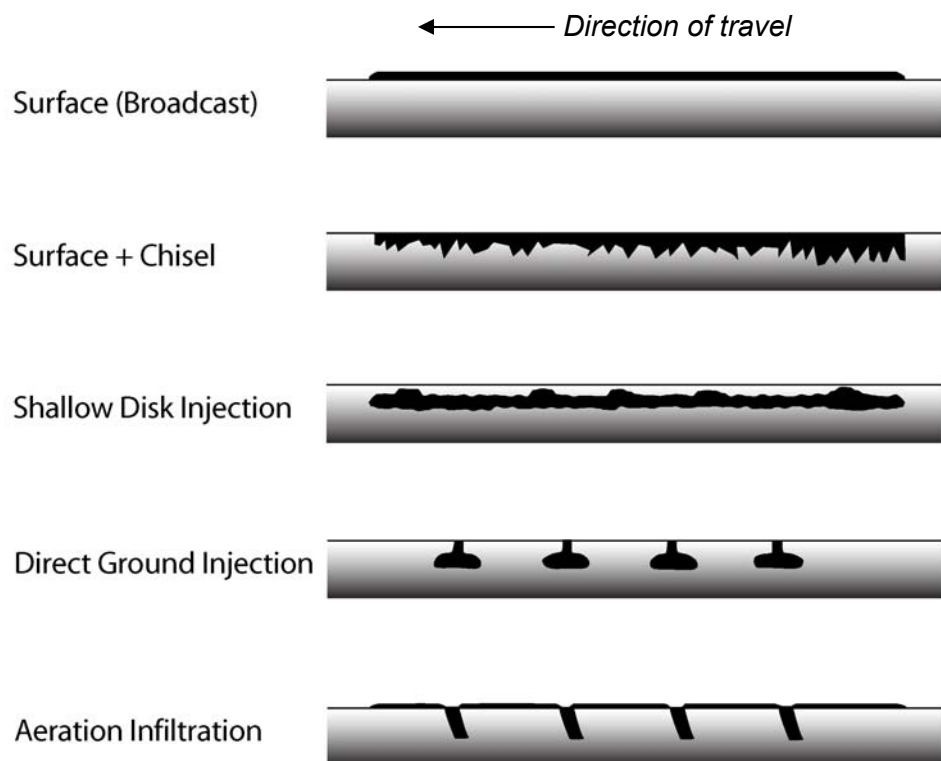
**Table 2.** Mean field olfactometry odor panel D/T sorted by application method and time.

Time	0 h Pre-application	<1 h	2-4 h	24 h	Composited over all times
<b>Method</b>	<b>Field Olfactometry Odor Panel D/T (Log BET<sub>10</sub>)<sup>1</sup></b>				
DGI	0.151 ± 0.0b <sup>2</sup>	0.633 ± 0.133b	0.406 ± 0.275b	0.226 ± 0.135bc	0.3498 ± 0.247d
Aeration infiltration	0.438 ± 0.31a	0.942 ± 0.197a	0.430 ± 0.133b	0.622 ± 0.290a	0.6110 ± 0.319b
Shallow disk injection	0.151 ± 0.0b	0.678 ± 0.429b	0.224 ± 0.168c	0.280 ± 0.185b	0.3338 ± 0.318d
Surface	0.151 ± 0.04b	1.113 ± 0.215a	0.784 ± 0.3214a	0.690 ± 0.204a	0.6847 ± 0.409a
Surface + chisel	0.151 ± 0.0b	0.549 ± 0.252b	0.692 ± 0.250a	0.335 ± 0.209b	0.4320 ± 0.289c
Control	0.151 ± 0.0b	0.151 ± 0.0c	0.181 ± 0.103c	0.151 ± 0.0c	0.1604 ± 0.053e

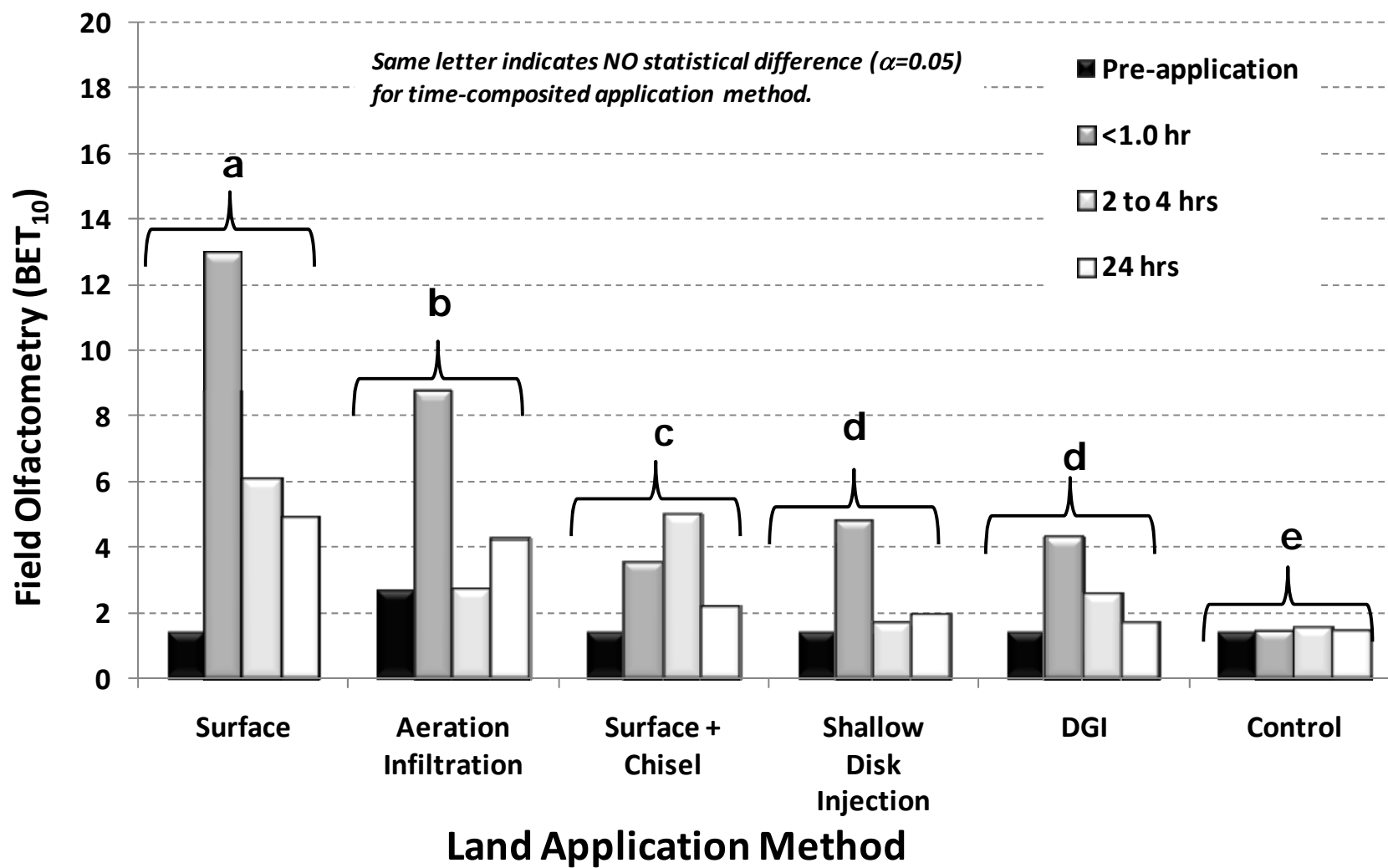
<sup>1</sup>BET<sub>10</sub> = Odor panel best estimate threshold (ASTM E669) for field observations collected over 10 min period.<sup>2</sup>Standard deviation values followed by the same letter are not significantly different ( $\alpha = 0.05$ ).**Table 3.** Mean laboratory olfactometry DT and RT results for whole air samples collected 2-4 h following manure application.

Method	Laboratory Olfactometry Odor Panel (Z <sub>ITE,pan</sub> ) <sup>1</sup>	
	Detection Threshold (DT)	Recognition Threshold (RT)
DGI	1.62 ± 0.11b <sup>2</sup>	1.32 ± 0.11c
Aeration infiltration	2.11 ± 0.36a	1.80 ± 0.25a
Shallow disk injection	1.84 ± 0.15b	1.58 ± 0.14b
Surface	2.23 ± 0.30a	1.89 ± 0.28a
Surface + chiseling	2.23 ± 0.30a	1.86 ± 0.25a
Control	1.35 ± 0.00c	1.05 ± 0.00d

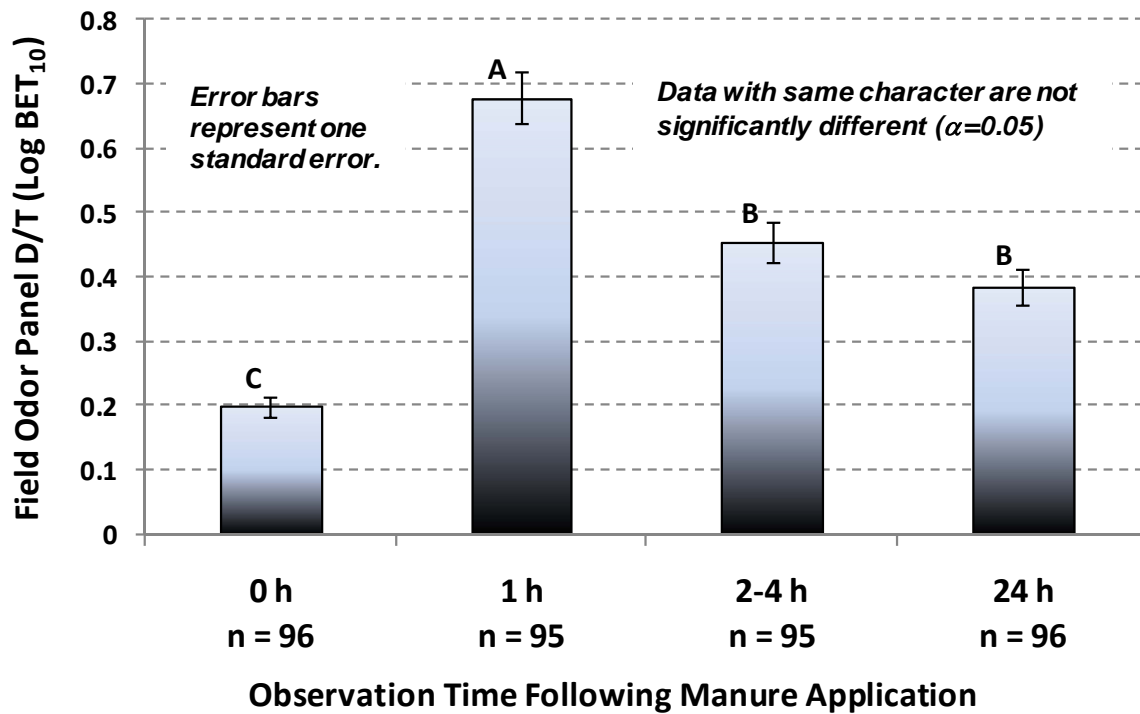
<sup>1</sup> Z<sub>ITE,pan</sub> = Odor panel dilution factor per EN13725:2003.<sup>2</sup>Standard deviation values followed by the same letter are not significantly different ( $\alpha = 0.05$ ).



**Figure 1.** Manure incorporation/ surface exposure for the various field application methods.



**Figure 2.** Field olfactometry odor panel results for pre-application, <1 h, 2-4 h, and 24 h following land application.



**Figure 3.** Field olfactometry log BET<sub>10</sub> D/T values for all sampling periods and field application methods combined.

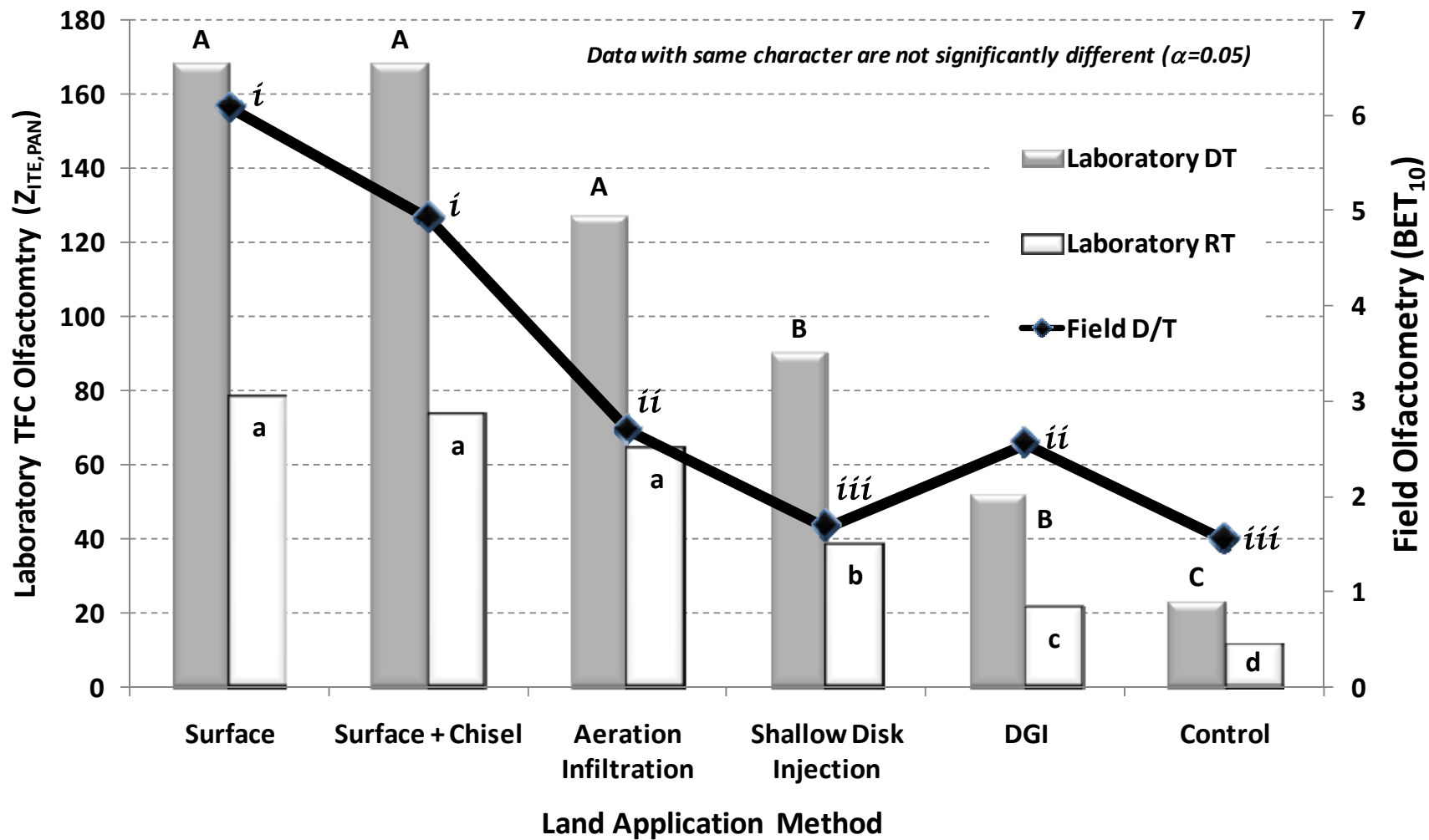


Figure 4. Comparison of laboratory olfactometry detection (DT) and recognition threshold (RT) odor panel results versus field olfactometry dilution-to-threshold (D/T) odor panel findings for observations 2-4 h following land application.